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ON THE LIMIT OF SUBDIVISION BY TRITURATION AND SOLUTION,

AND THE PRINCIPLES ON WHICH THE LIMIT MAY BE INDEFINITELY EXTENDED.

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If any coarse and dry substance is triturated by itself, it will continue to be permanently divided and subdivided to a certain, but limited extent. For beyond that, the blow would either leave the parts so near each other, that they would instantly reunite by the power of the cohesive forces and again become one solid body, or would drive these newly separated parts against others or against each other, and effect their union by bringing them within the sphere of cohesion.

If a flint stone were pulverized in a mortar, it would at length become so fine, that some of the finest of these invisible flint stones would, after any farther division, be soon reunited. All that would be necessary for their reunion and the restoration of their previous hardness, would be, to bring the parts or their mutually attractive poles, as near to each other as they had been before their separation; for the strength of their cohesion depends on the degree of their proximity. The approximation and union of some of these smaller than microscopic pebbles, would be promoted by the pressure of the pestle: the same blows that severed some, would unite others, so that the average size of the parts would remain unchanged.

I have referred to poles, believing that the cohesion of all atoms and of all groups sufficiently small, depends on polarity and is a crystallizing force, and probably magnetism itself in its most elementary form. But similar principles apply to my theory of comminution and similar language may be employed, whether we regard the cohesive force as residing on all sides of the groups, or only at certain poles. For if a group were surrounded by ma-

ny others within its sphere of cohesion, some of their poles would be in a position favorable to union, and others be brought into that position by rotation, as would be the case with a multitude of small magnets thrown together promiscuously.

In experiments with the solar microscope, twelve or fifteen years since, I saw and exhibited to the Senior class of Union College, thousands of instances of rotation, attraction, and induction, in the crystals of camphor formed from the tincture placed on a small plate of mica and exposed to solar radiation. When the sky was very clear and the radiation intense, the phenomena became confused by the rapidity of the crystallization, and it was necessary to dilute the saturated tincture with about five times its bulk of alcohol, in order that these phenomena might be exhibited in all their distinctness and beauty. Thin clouds permitted the use of the undiluted tincture, and intermediate states of the sky required intermediate degrees of dilution. A description of these interesting phenomena was given in the "Report of the Regents of the University of the State of New York, for the year 1836," pp. 207 to 209, and an abstract in this Journal, vol. xxv. I here refer to them as evidence of the polarity of minute groups.

In resuming the consideration of pulverized flint, let us suppose the powder had attained such an extreme degree of fineness as can be given to it by a process which I shall describe, and let us suppose that it could be separated from other substances and subjected in mass to the blows of the pestle; the effect would be like that of pounding a quantity of clean leaden shot: we should stick them together in large masses. If we had a sufficient quantity of such a powder confined in a cylinder and pressed by a piston, we could probably unite it all into one flinty rock, perhaps defective in hardness at some points, from want of the requisite position of the poles.

I have taken an extreme case, in order to enable the reader more easily to conceive of the principle on which the limitation to comminution in the ordinary process of pulverization depends. The powder of any substance, pounded or rubbed by itself in a mortar, would attain a limit of fineness, beyond which its subdivision could not be carried by the combined labor of all mankind operating in the same way through all ages.

A sliding motion of the pestle enables us to go a little farther before we reach this limit, not only because it subjects small isolated masses more directly and efficiently to the dividing force, but because it allows fewer opportunities for the reuniting force of cohesion to come into play, by keeping the newly divided parts at a greater distance from others already divided. But in this mode of operating also, the limit will be as surely reached as in pounding. For when a certain degree of fineness has been effected by this rubbing process, the stratum of powder beneath the

pestle will either be so thin as to elude its dividing action, or so thick that the number of parts which are pressed against each other by its strokes and reunited, will equal the number divided by the same strokes. At this stage, the comminution will cease; and the trituration, ever so skillfully conducted, and carried on forever, could not reduce the powder to any greater degree of fineness.

Is there any way in which this limitation may be obviated, and the fineness of the powder indefinitely increased? Yes: it may be done by successive mixtures with some other substance, using thorough trituration after adding each portion. This method is of universal application; yet for the sake of convenience and precision, I shall assume particular substances and a particular proportion. Suppose a flint powder to be rendered as fine as it is possible to make it by rubbing it per se; and suppose one grain of this to be triturated with ninety-nine grains of ordinary loaf-sugar, or of the harder—and therefore better—non-medicinal substance, sugar of milk. Suppose, by means of stirring with a spoon or spatula, the flint powder be intimately mixed with the pulverized sugar, so as to be uniformly distributed through it, before the trituration is commenced. [This is not requisite in practice, but simplifies the investigation.] Then each of the microscopic flint stones is surrounded by ninety-nine times its weight of sugar, which keeps them at nearly five times their former distance from each other, as estimated from centre to centre. What is the consequence, if trituration be commenced under these circumstances? A new and far more minute division must result.

The sugar serves two purposes, viz. first, to divide the flint, and secondly, to keep it divided; it contributes both to effect and preserve the division. It serves the first of these purposes in more than one way. First, it aids division by mechanical collision, when driven against the flint by the pestle. It in this way aids the fracture; as the stroke of one body may often be made to break another though harder than itself. Thus a quartz pebble can be crushed between two large pieces of marble, and a still smaller one between two large pieces of sugar of milk. The advantage given by magnitude, suggests that the sugar employed will be more effectual if selected in a state coarser than that of the harder powder which it is employed to comminute. In later stages it will necessarily have this advantage. Secondly, the sugar may aid the division by its affinity, its attraction for the flint. Thus whilst some of the pieces of hard sugar are acting as hammers and wedges, and tending to separate an intermediate piece of flint into two pieces, other pieces of sugar, situated in the line in which the fragments of flint when divided tend to move, may by their affinity draw the fragments in the direction in which the other pieces of sugar push them, and thus both kinds of force conspire to effect their separation.

Having hitherto considered the direct agency, I now proceed to the indirect; viz. the promotion of farther division by keeping separate the parts already divided. The sugar favors comminution by keeping the pieces of flint at a distance from each other, and thus preventing that reunion which would be continually taking place in the parts of the pure flint powder pressed against each other by the pestle. The parts when once divided, are by the interposition of the sugar prevented from again coming within the sphere of mutual cohesion, until the subdivision has been carried to a much greater extent than would have been practicable in triturating the flint by itself.

A limit will, however, be ultimately reached, even under these circumstances. As the subdivision continues, the mutual distance of the pieces of flint diminishes, and some portions are ultimately brought again within the sphere of cohesion, and made to unite by the same strokes of the pestle which divide others. When the number united by each stroke equals the number divided by the same, the fineness can no longer be increased by continuing the friction.

The only way in which the fineness can be increased, is by another mixture. If a grain of this powder is mixed and triturated with ninety-nine grains of hard sugar, like that previously employed, a still more minute division of the flint is effected; but, for the same reasons as in the preceding case, we ultimately reach the limit, beyond which it is impossible to pass without a new mixture or dilution. By the continued repetition of operations similar to those above described, an inconceivable degree of comminution may be effected.

We may not be able to determine theoretically the number of subdivisions which are practicable at each stage. But if subdivision did not affect the intensity of cohesion, and if the division were already carried so far, that the magnitude of each piece was so small compared with the magnitude of its sphere of cohesion, as to produce no sensible influence in the estimate, then it would appear from the theory above given, that the maximum comminution at each stage would be in the ratio of one hundred to unity. So that flint, silex, gold, mercury, or any other substance prepared in this way with sugar or saccharum lactis—or some other suitable substance—would, at each succeeding stage of the process, be divided into parts, all of which would be one hundred times as numerous, and each of which would be the one hundredth part as large as the parts in the preceding stage. This increase in the number, however, supposes that every grain of the preceding one hundred is subjected to a similar operation. If, as before supposed, only one grain at each stage is taken from the hundred and subjected to this operation, then the parts of each trituration will be equally numerous, but increase in fineness at each stage

in the ratio of one hundred to one; and a grain of the thirtieth trituration of gold would contain as many minute pieces as a grain of the third trituration.

But I am convinced that the intensity of some properties of substances is greatly increased by comminution. If the sphere of cohesion is thus increased, the maximum comminution will fall below the above estimate. I believe that in practice the comminution will fall below it, not only for the above reason, but also because the trituration, though continued sufficiently long to bring most of the parts to the maximum size, will be discontinued before every part is equally reduced.

Hence microscopic observations are liable to lead to erroneous conclusions. Dr. Mayerhofer has seen scores of millions of pieces of metal in a single grain of the sugar with which it had been triturated to form the third trituration. The number varied with different metals. From the considerations which I have above stated, as well as from others, I am convinced that the number of invisible pieces far exceeded the number of visible ones. Those only were seen which had escaped the full effect of the dividing forces. The minimum groups in the third trituration are not objects of microscopic vision. From the wide range of magnitude in the visible pieces, as well as from the appearance, on close inspection, of pieces at first invisible, Dr. M. justly concluded, that in the first trituration of precipitated gold, "the metal is divided into particles so small as to be invisible under a glass magnifying 14,000 times." He "examined the fourth trituration by a power magnifying 90,000 times, and it was evident that the diminution of the particles progressively increased; the smallest gold molecules appeared yellow, and the metallic lustre was not to be mistaken." The diminution here refers to the visible ones. As the conclusions which I have drawn in regard to the facility of reunion, the limit of comminution, and the intensity of properties, refer to those more numerous groups which are so small as to be invisible by the most powerful microscope, it would be impossible either to establish or refute them by microscopic observations.

The above method of trituration has great advantages for effecting a minute division of substances. I have shown, that in order to triturate a substance to powder of a certain degree of fineness, it is necessary to mix it with a sufficient quantity of some other substance; and that the requisite quantity of this admixture increases with the fineness required. Such a degree of fineness can be specified, as would render the labor of comminuting a single grain impracticable, even if the requisite amount of material for the admixture could be obtained. The labor of the whole human race operating through all ages since the creation of man, could not thoroughly triturate a single grain of one substance with a decillion grains of any other substance. Yet the

same degree of fineness as would be effected by such an operation may be effected by one man in thirty hours, and with scarcely three thousand grains of auxiliary material. If we suppose him to commence with one grain of the substance to be comminuted, and allot one hour to each of the thirty stages, the resulting powder would contain a portion of the original grain, in a state of fineness equal to that in which the whole grain would have existed in a decillion grains equally well triturated.

The above theory is original; but this process of trituration is not. Most persons who have practiced it, have not considered the only direct object of it to be comminution; and if any have, they have not explained, on physical principles, the mode in which it is effected, nor the limit which we encounter by the ordinary process, nor the peculiar advantages of this process in avoiding that limit.

I shall not here state particularly the effect and ultimate object of the comminution effected by the above process. In my opinion it must develop a species of magnetism, and the minutest pieces thus obtained must be intensely magnetic. As a branch of physical inquiry, this subject has especial interest at the present time, when the attention of philosophers is becoming more and more directed to molecular forces, and the peculiar properties of small masses. The recent experiments of Sir G. C. Haughton have afforded new evidences of the identity of molecular magnetism and cohesion, and new proofs that all bodies are magnetic when they are rendered sufficiently small.* What intensity of magnetism may not be expected in bodies as minute as those which can be suspended fifty or a hundred miles above the earth's surface, in air so rarified as to be incapable of reflecting any sensible quantity of solar light! I believe this intensity to be far more than sufficient to compensate for the reduction of the quantity of ponderable material, and to be adequate to the production of the most brilliant aurora borealis. In this case there is probably a crystallization, a change from the fluid or aeriform state to that of minute solids, whose magnetism ultimately becomes latent after aggregation in larger masses.

I believe it to be a general law of nature, that certain properties possessed by small groups of molecules, are marked or rendered latent by the proximity of a sufficient number of similar groups; and that, conversely, properties or powers are developed by the division of substances.

It would seem that bodies rendered so inconceivably minute as they can be by the process of trituration above described, must possess a most intense magnetic state, although their circumstances are evidently such as to preclude the application of

* Lond. and Edin. Phil. Jour., for June, 1847.

the ordinary tests. As the examination of any known mode of testing the power of such preparations would involve physical and professional considerations, I shall do nothing more than submit the mechanical explanation of the comminuting process to the consideration of natural philosophers, trusting that they will consider the subject interesting as a branch of physical investigation.

Similar principles are applicable to *subdivision by solution.*

It is generally believed, that the simple solution of a substance effects the minutest division of it which is practicable. In calling in question the correctness of this notion, I am aware of the strength of the prejudices to be encountered—prejudices both of the senses and intellect. For deciding such a point, there is no adequate delicacy in human vision nor in the instruments of physical research; nor is the human mind so constituted, as to be capable of any adequate conception of the minuteness of ultimate atoms, or of the infinite diversity of magnitude existing among infinitesimals.

The following are the views which I take of solution, and which I am desirous of submitting to the consideration of natural philosophers. In a saturated aqueous solution of any salt, I consider the molecules of the salt as existing in hard solid groups or masses of the salt, suspended at equal distances in the water, which exceeds the salt in quantity. Each mass of salt consists of innumerable particles. It is impossible to make these groups smaller, either by the affinity of the water or by any mechanical force, as long as the quantity of water remains the same. If they were sundered, they would instantly reunite. For, any division of the solids into smaller groups would diminish their mutual distance, and consequently increase their mutual attraction; whilst the quantity of water which surrounds each mass is diminished in quantity, and hence possesses less attractive force for resisting the reunion of the solids, than it had when they were in larger masses; even then this affinity was but just sufficient to keep them separate. Therefore any division would be followed by instantaneous reunion, both on account of an increase in the cohesive forces, and a diminution of affinity. The ultimate molecules are not separately invested with the water, but united in hard and complex masses, which cannot remain suspended within a given mutual distance.

How can this limitation be obviated, and the size of these complex molecules be progressively and indefinitely diminished? This may be effected by successive dilutions. To select the same proportion as in trituration, suppose one drop of the saturated solution to be put into ninety-nine drops of water. This water exerts its affinity as an antagonist to the cohesion of the solid groups of salt, and effects their dismemberment to a far

greater extent than was practicable in the saturated solution. Brisk agitation favors uniform diffusion and rapid dismemberment, and more promptly in a vessel but partly filled. But the process of disintegration commences instantly, before the diffusion is complete. To simplify the investigation, let us suppose the drop to be uniformly diffused before any disintegration of the groups commences. The groups would be at nearly five times their original distance, and each mass or group of salt would be surrounded by one hundred times as much water as in the saturated solution. This state of things could not remain a moment; especially if the disruptive power of the affinity of this increased quantity of water, were aided by a mechanical succussion, as strong as that to which the saturated solution had been subjected. For the equilibrium, before existing between cohesion and affinity, will be disturbed by that increase of the latter which results from the increase of the liquid; and the suspended solids will each be sundered into numerous smaller solids. But the salt is not divided into its smallest particles; nor could it be by the most violent succussion. The vibrations caused by jars, transiently increase the distance of some particles of each group, and approximate them to the liquid, and thus give affinity a preponderance over cohesion. In this way succussion aids division. But to carry division by this means beyond a certain point, effects no permanent change; as the particles will instantly reunite by the preponderance of cohesion over affinity.

If a drop of this solution is shaken with ninety-nine drops of water, a new subdivision of the molecules takes place, on the same principle. By repeating this process, the groups may be rendered inconceivably small, and this magnitude progressively and indefinitely diminished. I doubt whether those who have practised it have understood its immediate object, or the mode in which it is attained.

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